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Laser Doppler scanners for measuring flow over terrain

Jakob Mann, Torben Mikkelsen and Mike Courtney

Wind Energy Department, Risø DTU, Roskilde, Denmark

January 2011 – EERA workshop on wind conditions, Porto,
Portugal

Doppler lidar instruments

ZephIR: continuous wave, WindCube: pulsed



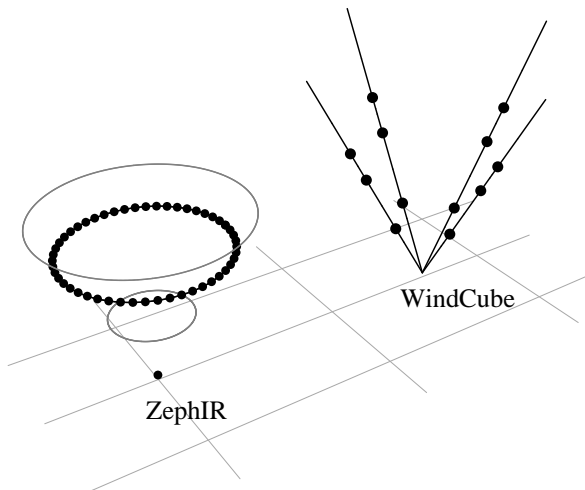
Doppler lidar instruments

ZephIR: continuous wave, WindCube: pulsed



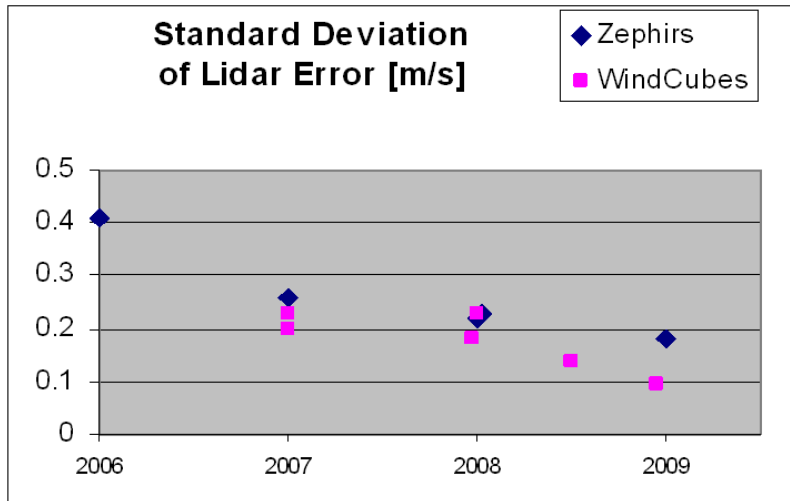
Doppler lidar instruments

ZephIR: continuous wave, WindCube: pulsed



Mean wind speed measurements over flat terrain

ZephIR and WindCube



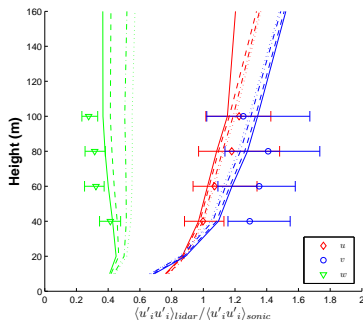
(Courtesy of et al. 2008 & 2011)

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Laser Doppler scanners for measuring flow over terrain

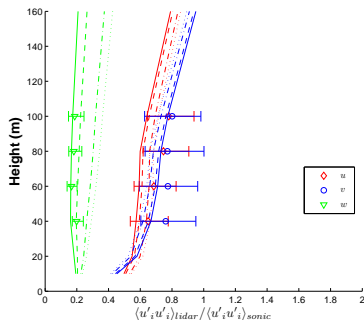
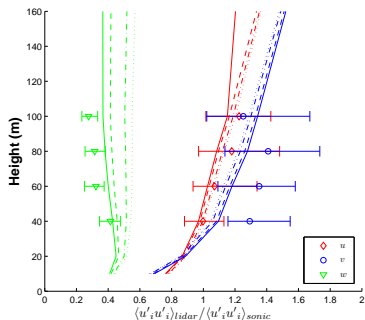
Turbulence measurements over flat terrain works less well

Systematic error under different atmospheric stability conditions; WindCube: Unstable and stable

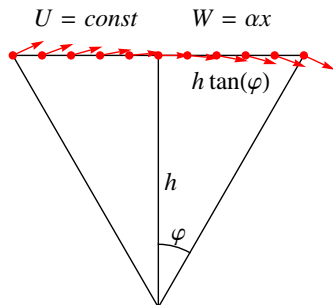


Turbulence measurements over flat terrain works less well

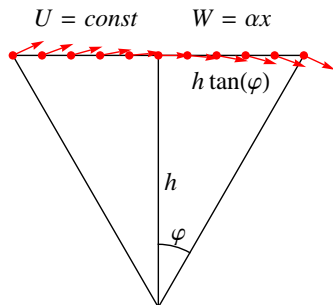
Systematic error under different atmospheric stability conditions; WindCube: Unstable and stable



Conical scanning in non-homogeneous flow

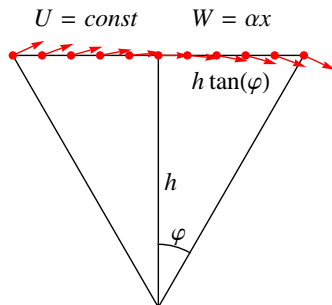


Conical scanning in non-homogeneous flow



$$\begin{aligned}
 v_{up} &= (-\sin \varphi, \cos \varphi) \cdot (U, -h\alpha \tan \varphi) \\
 &= -U \sin \varphi - h\alpha \sin \varphi \\
 &= -(U + h\alpha) \sin \varphi
 \end{aligned}$$

Conical scanning in non-homogeneous flow



$$v_{up} = (-\sin \varphi, \cos \varphi) \cdot (U, -h\alpha \tan \varphi)$$

$$= -U \sin \varphi - h\alpha \sin \varphi$$

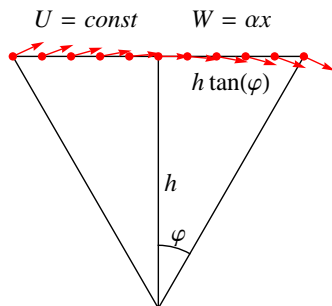
$$= -(U + h\alpha) \sin \varphi$$

$$v_{down} = (\sin \varphi, \cos \varphi) \cdot (U, h\alpha \tan \varphi)$$

$$= U \sin \varphi + h\alpha \sin \varphi$$

$$= (U + h\alpha) \sin \varphi$$

Conical scanning in non-homogeneous flow



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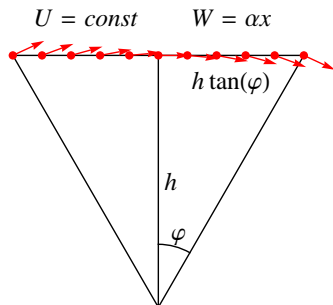
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$$U_{lidar} = \frac{v_{down} - v_{up}}{2 \sin \varphi} = U + h\alpha$$

Conical scanning in non-homogeneous flow



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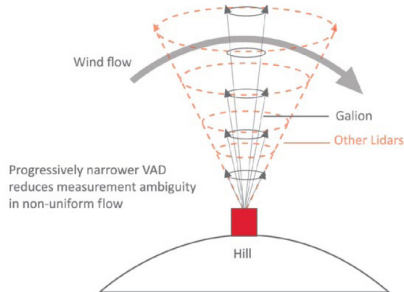
$$U_{lidar} = \frac{v_{down} - v_{up}}{2 \sin \varphi} = U + h\alpha$$

Does not depend on φ !

Smaller opening angle φ

A suggested solution

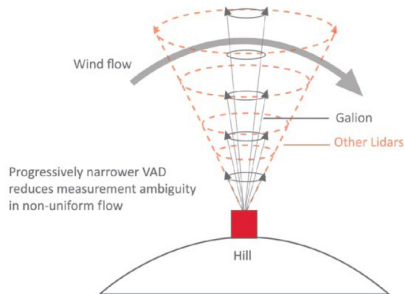
Ridge



Smaller opening angle φ

A suggested solution

Ridge

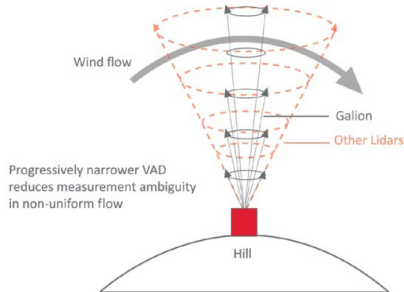


⚡ Should not work in theory

Smaller opening angle φ

A suggested solution

Ridge



⚡ Should not work in theory

⚡ Has not been demonstrated in practice

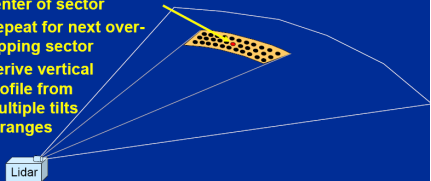
Mapping wind speed over complex terrain

Lockheed Martin Coherent Technologies and RES



VAD Technique Applied to Volumetric Long Range Data

- Collect radial velocity data over a large spatial region
- Scan in azimuth at a constant elevation angle --- a tilt
- Apply VAD algorithm to the annular sector and derive vector velocity estimate for center of sector
- Repeat for next overlapping sector
- Derive vertical profile from multiple tilts & ranges



22 June 2009 - 14

⚡ Still systematic errors on wind components “perpendicular” to the beam

Other possible solutions

- Use flow models to calculate correction
 1. Bingöl et al 2009 *Met Zeit* (WAsP Engineering)
 2. Mean W measurements: Dellwik *et al*, 2010, *BioGeoSciences*
 3. Natural Power at EWEC 2010 (Ventos)

Other possible solutions

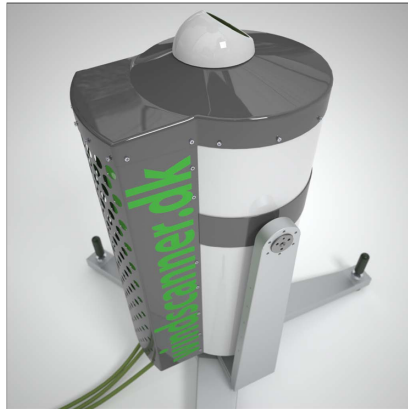
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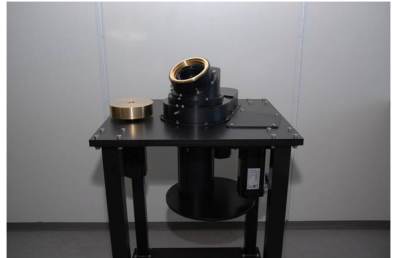
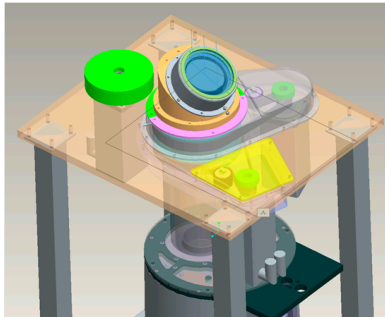
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- Assimilate measured radial components in
 1. WAsP or WAsP Engineering
 2. Other wind resource estimation software
- *Use three lidars!*

Short range wind scanner

Combine three ZephIRs and move the beams fast



Scanning performed with a patented double prism system





Long range wind scanner

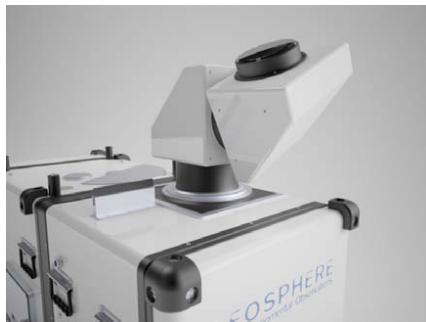
Combine three WindCubes and move the beams sedately



Specifications of long-range wind-scanner

WLS70 + Risø DTU/Leosphere scan head

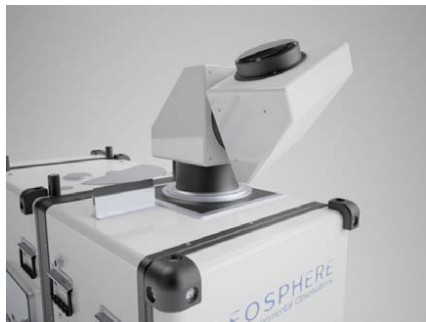
- Range: 1.5 – 5 km, depending on sampling time and aerosols



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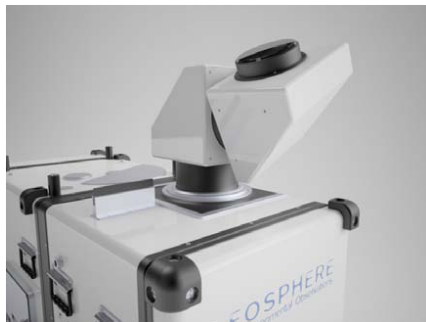
- Range: 1.5 – 5 km, depending on sampling time and aerosols
- Resolution: 55 m along beam, 1 – 10 measurements/s

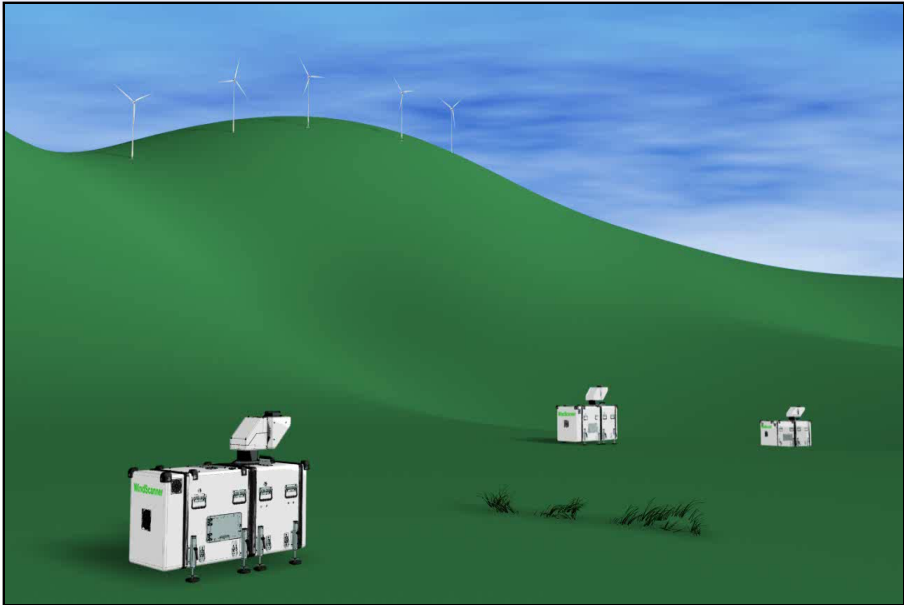


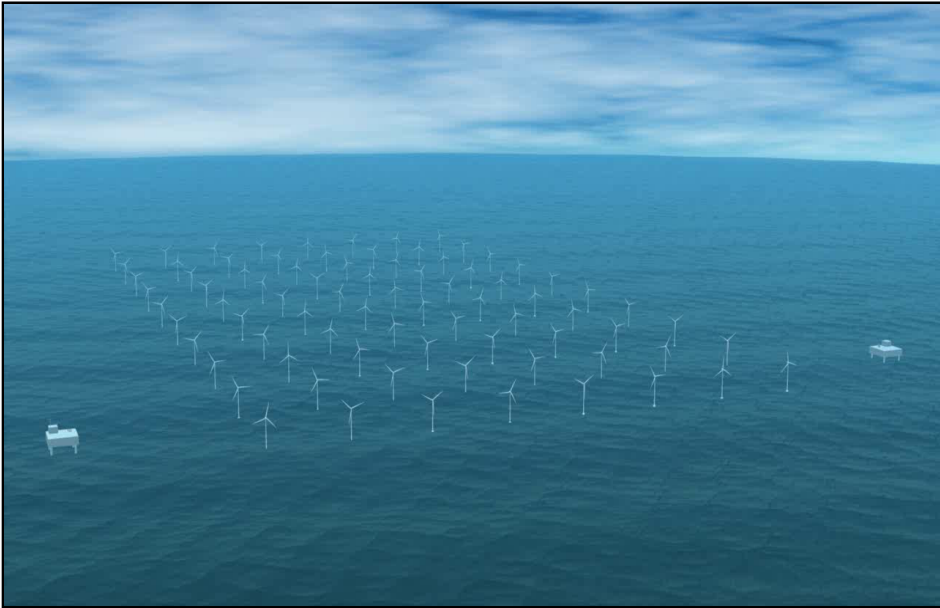
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WLS70 + Risø DTU/Leosphere scan head

- Range: 1.5 – 5 km, depending on sampling time and aerosols
- Resolution: 55 m along beam, 1 – 10 measurements/s
- Scanner: <2 mrad, velocity $50^\circ/\text{s}$, acceleration $100^\circ/\text{s}^2$







Conclusion

- In contrast to mean wind speed, turbulence from lidars is biased even over flat terrain.

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Conclusion

- In contrast to mean wind speed, turbulence from lidars is biased even over flat terrain.
- It is necessary to use three lidars for accurate wind measurements over complex terrain
- We develop two three-lidar systems:
 - A short range system based on Natural Power's ZephIRs
 - A long range based on Leosphere WindCubes.